WT-1678

OPERATION HARDTACK—PROJECT 2.10

RESIDUAL RADIATION from a VERY-LOW-YIELD BURST (U)

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ABSTRACT

This project participated during Shots Quince and Fig to determine the radiation intensities of contaminated areas resulting from a very-low-yield, surface nuclear detonation.

This objective was accomplished by: (1) monitoring the crater and lip shortly after detonation, (2) performing helicopter-to-ground surveys at preselected points, (3) making a number of ground surveys during and after sample collection, (4) determining the gross gamma decay of the residual radiation from collected fallout samples, and (5) documenting the alpha contamination.

The area at ground zero for Shots Quince and Fig at Eniwetok Proving Ground was prepared by substituting soil from the Nevada Test Site (NTS) for the coral soil within the expected crater volume and over areas that were expected to contribute debris to the cloud.

Shot Quince did not go nuclear and created only alpha contamination. Decontamination of a 30-degree sector extending 300 feet downwind from ground zero would have been necessary. The highest alpha air concentration was less than 2 percent of the 1-hour emergency exposure of 2×10^{-8} $\mu c/cm^3$.

The radiation intensities at the lip and crater of Shot Fig were above 10,000 r/hr at H+26 minutes, a level that would have necessitated avoidance of these areas by troops.

The areas contaminated to levels of 200 r/hr were approximately the same size as predicted by the present scaling laws. However, this is probably only true if a weapon similar to the Fig device is fired under identical conditions, because the activity induced by Na^{24} in the fallout was a significant contributor to the total dose rate.

The fallout consisted of NTS soil and coral particles and the size fractions above 420 microns contained most of the activity. Several types of particles were observed. However, fused silicate particles in the 420-to-840-micron fraction contributed 95 percent of the total activity, although they were only 9 percent of the total weight.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVE

The objective was to determine the radiation intensities of contaminated areas resulting from a very-low-yie[redacted] surface nuclear detonation.

This objective was accomplished by: (1) monitoring the crater and lip shortly after detonation, (2) performing helicopter-to-ground surveys at preselected points, (3) making a number of ground surveys during and after sample collection, (4) determining the gross gamma decay of the residual radiation from collected fallout samples, and (5) documenting the alpha contamination.

1.2 BACKGROUND AND THEORY

1.2.1 Definition of Surface Burst. A surface burst is defined as one that occurs on or above the surface of land or water and whose fireball (at maximum brilliance) touches the surface.

1.2.2 Fallout Contamination. The basic fallout phenomena associated with a low-fission-yield surface burst are expected to be essentially the same as those for a high-fission-yield surface burst. For a low fission yield, however, the quantity of fission products will be smaller and the area that will be contaminated will be proportionately smaller.

Nature of Contamination. In a surface detonation the fireball incorporates some of the surface material, which becomes contaminated with the radioactive products of the nuclear explosion and is then precipitated to the earth as fallout contamination. The fallout radioactive contaminants will consist of: (1) fission products, (2) neutron-capture products formed in the device materials, and (3) neutron-capture products formed in the nearby land or water. The first of these types predominates over the others.

The fraction of the total radioactive products of the nuclear explosion that appears in the local fallout depends upon the extent to which the fireball touches the surface. Thus, the proportion of the available activity increases as the height of burst decreases and more of the fireball comes into contact with the earth. Where the device is actually on the surface when it explodes, at least 50 percent of the total residual radioactivity will be deposited on the ground within the local fallout area. In a surface burst, large amounts of earth, dust, and debris are taken up into the fireball in the solid, liquid, and gaseous states. This material becomes intimately mixed with the fission and activation products. As a result, there is formed upon cooling a tremendous number of small particles contaminated to some distance below their surfaces with radioactive matter. In addition, there are considerable quantities of particles, ranging from large lumps to fine dust, that are surface coated with fission products.

Shape of Contamination Pattern. Provided the wind is not excessive, the large particulate material, as it falls, will form a roughly circular pattern around ground zero. The center of this circular pattern, called the "ground-zero circle," will usually be displaced somewhat from ground zero by the wind. Most of the contaminated material, forming the ground-zero circle, descends within a short time. The smaller particles in the atomic column and cloud are, however, carried upward to a considerable height and may spread out some distance before

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Chapter 2
PROCEDURE

2.1 SHOT PARTICIPATION

The project was originally scheduled for participation only during Shot Quince, a surface burst of a very-low-yield device on Site Yvonne of the Eniwetok Proving Ground (EPG). Because this shot did not go nuclear, the project then participated in Shot Fig at the same ground zero and with the same instrumentation array. The station layout is presented in Figure 2.1.

For both shots, a conically shaped excavation, 30 feet in diameter and 8 feet deep, which was expected to contain the crater volume, was filled with soil from Area 10 at Nevada Test Site (NTS) (Reference 15). This was done in order to minimize confusion in interpreting the fallout results, because most of the fallout data for yields below the megaton range has come from bursts over NTS soil.

2.2 SUMMARY OF OPERATIONS

Gamma dose-rate readings 3 feet above the ground of the complete available land area were determined with the helicopter-to-ground aerial-survey instrument and with AN/PDR-39 survey meters. The data should be accurate to ± 20 percent.

It was intended to pull the probe of a Jordan survey meter toward and into the crater to determine the gamma radiation existing in and around the crater.

The amount of alpha contamination was obtained by monitoring concrete slabs placed at various locations and measuring the filter paper from the air samplers. The readings from the concrete surface were reduced to microcuries per square centimeter and those from the air samples to disintegrations per minute per cubic meter. The results are estimated to be accurate to ± 30 percent.

Fallout samples were obtained by means of open-close and open gross-fallout collectors. These samples were weighed and the amount of fallout per unit area and the relative activity per unit weight calculated. Three of the fallout samples were used to determine the gross gamma dose decay rates and activity of the size-fractionated samples. Gamma spectra and radiochemical analyses were performed, and the fallout particles were classified according to physical appearance.

2.3 INSTRUMENTATION

Instrumentation consisted of the helicopter-to-ground survey instrument, fallout collectors, crater-survey instrument, air samplers, concrete slabs, gas-flow proportional alpha counter, AN/PDR-39 survey meters, and aerial-survey markers.

2.3.1 Helicopter-to-Ground Survey Instrument. The aerial-survey equipment is illustrated in Figure 2.2. It consisted of a radiation detector mounted in a probe that could be lowered from a helicopter by means of a special cable and a powered reel to take readings 3 feet above the ground. The instrument and its use is described in detail in Reference 16.

The instrument was calibrated before and after each use with a 500-curie Co^{60} source, as described in Appendix A.

2.3.2 Fallout Collectors. Two types were used: open-close and open gross-fallout. The open-close collectors had a metal support framework and a conical liner with a door covering the opening. The liner had an opening approximately 2 feet in diameter at the top. In the bottom of the cone was a stainless-steel filter, 4 inches in diameter, which covered a small

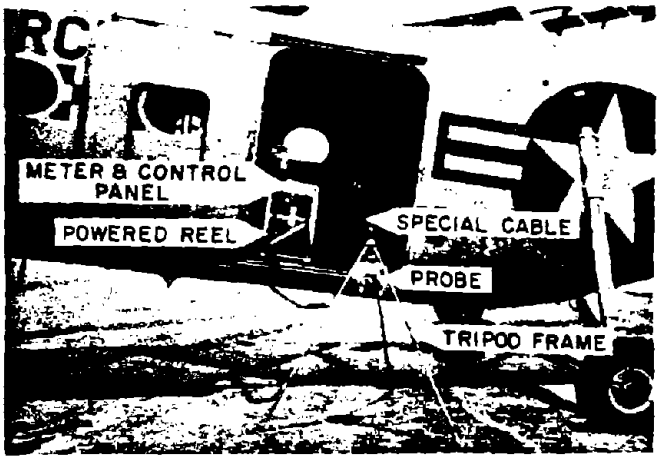

Figure 2.2 Aerial-survey equipment.

hole leading to a polyethylene bottle. Figure 2.3 shows the collector with the door open, and Figure 2.4 shows it with the door closed. The door opened and closed with a sliding action. It had a notched strip rack on its top and was driven by a 24-volt dc motor through a chain-and-gear-drive system. The control system was activated by the closing of a relay in an Edgerton,

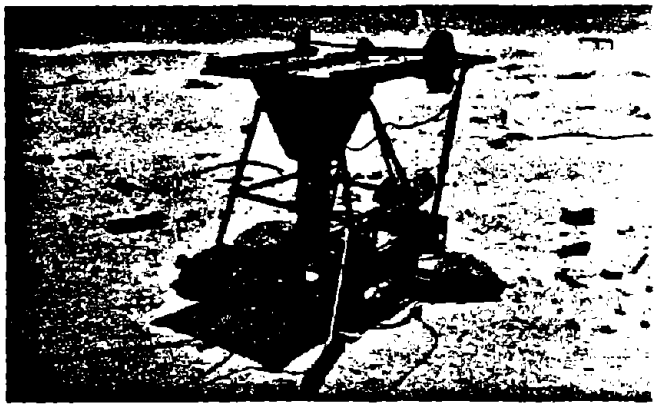

Figure 2.3 Open-close collector with door open.

Germeshausen and Grier, Inc. (EG&G) hard-wire signal system, 1 second before the detonation. During recovery, the door was opened manually, and a cover was put on the cone liner. After the hose to the polyethylene bottle was disconnected, the cone liner and the bottle were removed from the gross collector and transported to the laboratory area.

The open gross-fallout collectors were polyethylene buckets 16 inches deep, each with a 13-inch-diameter opening and a polyethylene cover to prevent spilling of the fallout during transport to the laboratory area. Figure 2.5 shows an open-type-collector installation. The covers were removed manually a few hours before the shot and replaced during recovery.

2.3.3 Crater-Survey Instrument. The crater-survey instrument was a Jordan survey meter modified to record the radiation intensity on a Brown recorder. The probe, instead of being fastened to a tripod, was shock-mounted inside a fiberglass cylinder for protection when pulled

The primary alpha standards used were two disks coated with uranium oxide. The smaller source disintegrated at the rate of 3,224 dis/min and the larger at 45,577 dis/min in a 50-percent geometry. The probe could "see" only 86 percent of the smaller source and 80 percent of the larger source. Therefore, the sources were actually rated at 2,770 and 36,460 dis/min.

Secondary standards of uranium screwed into the inside of the instrument case were used in the field for quick instrument checks. These sources were rated at 1,750 and 2,500 dis/min.

The instruments were calibrated at the beginning of each day and at the end of each survey.

2.3.6 Alpha-Monitoring Surfaces. A broom-finish concrete surface, representative of a typical urban sidewalk, was chosen as the standard surface to be monitored. Forty-four of these surfaces, 10 by 10 by 2 inches, were used. Figure 2.9 shows one of these concrete slabs in place.

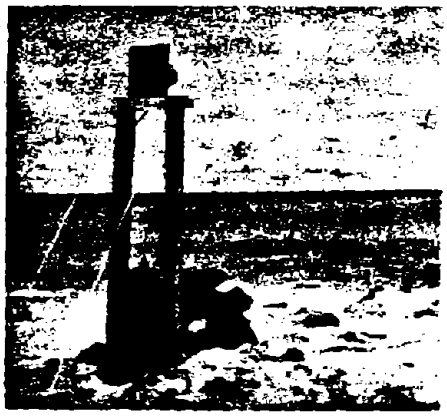

Figure 2.8 Field setup of air sampler.

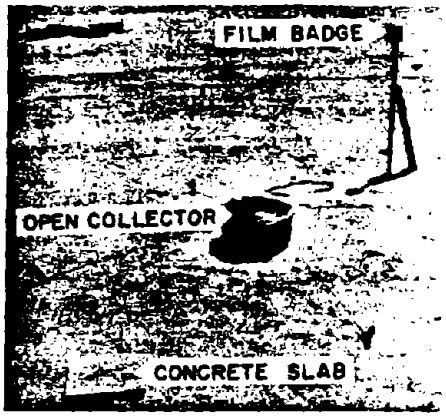

Figure 2.9 Concrete slab for alpha monitoring.

2.3.7 Gamma-Survey Meters. All gamma ground surveys were performed with the standard AN/PDR-39 survey meter. The instrument consists of an ionization chamber and measures the intensity of gamma radiation from 0 to 50,000 mr/hr on five scale ranges. It has an overall accuracy of ±15 percent.

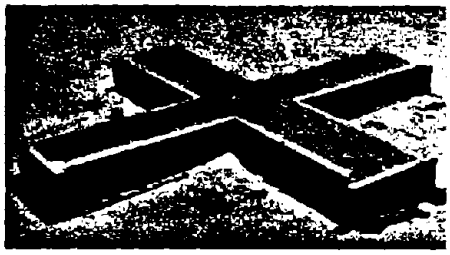

Figure 2.10 Aerial-survey marker.

2.3.8 Aerial-Survey Markers. The aerial-survey markers consisted of concrete crosses with each arm of the cross 3 feet long, 10 inches wide, and 6 inches thick. Figure 2.10 shows an aerial-survey marker in place.

2.4 TECHNIQUES

2.4.1 Gamma Ground Survey. The fallout-collector stations were used for ground-survey points. The early recovery parties of Projects 2.4, 2.9, 2.10, and 2.11 obtained gamma dose-rate readings during the recovery operations and at later times. These survey measurements were made while the meters were held approximately 3 feet above ground and away from the body.

2.4.2 Aerial Survey. At H+1 minute, an H-21 helicopter with Chemical Corps aerial survey equipment and two project personnel aboard departed Site Elmer for Site Yvonne and measured

the buckets were covered and the lids taped on securely. The sealed buckets were returned to the laboratory at Site Elmer. There they were uncovered and monitored in a fixed geometry, with the ionization chamber 2 feet from the top of the buckets. The fallout was then removed and the total weight and total activity determined. A few representative samples were used for determination of the gross gamma decay of the fallout.

No fallout samples were obtained from Shot Quince.

2.4.6 Weight and Activity of Fallout. The three gross-fallout samples which had the greatest activity (K-3, L-4, and N-2, Table A.6) were placed under a nitrogen atmosphere and transported to the CWL. There the samples were transferred to petri dishes, surveyed with a Technical Associates, Juno 3, alpha, beta, gamma survey meter, dried for 1 hour at 110 C, and weighed. A portion of each gross sample was examined with a Bausch and Lomb stereoscopic microscope for the presence of calcium oxide spheres. If calcium oxide was not present, a major part of each sample was subdivided into nine size-fractions by sifting for 30 seconds through 148-, 177-, 210-, 250-, 297-, 350-, 420-, and 840-micron U.S. standard sieves. Approximately 75 percent of each sieved fraction was dissolved as described in Appendix B for radiochemical analyses; the remaining portions were utilized in particle and gamma spectrometric studies.

2.4.7 Radiochemistry. In addition to the aforementioned dissolved size-fractionated samples, portions of the total samples were prepared for radiochemical analyses. Aliquots of the size-fractionated and total samples were analyzed for Mo^{99}, Ce^{144}, Ba^{140}, and Sr^{89}.

2.4.8 Examination of Individual Particles. Seven equal-weight samples of particles from the 420-to-840-micron size fraction from Station N-2 were weighed to ±0.05 mg. These samples were examined with a Bausch and Lomb stereoscopic microscope and their gross beta activity determined with a Sugarman-Los Alamos window flow counter RCL Mark 12 Model 11A. Samples were treated first with water and then with 6N HNO_3 to determine the fraction of the activity which could be leached out. The detailed procedures used for leaching and microscopic examination are given in Appendix C.

2.4.9 Gamma Spectrometry. Gamma spectra were taken of the three gross samples at H+51 hours, H+92 hours, and D+6 days to determine the dose-rate contributions from induced activities in the fallout. The samples were sealed in 5-ml beakers with rubber hydrochloride (pliofilm) and scotch tape, and placed on the center of a 3-by-3-inch NaI(T1) scintillation crystal joined to a 3-inch Dumont photomultiplier 6363 by ophthalmological jelly. The crystal and photomultiplier tube were canned as a unit in 5-mil aluminum that was coated on the inside with alpha alumina for maximum reflection. The scintillations produced in the crystal by the gamma rays were seen by the photomultiplier tube and the resulting pulses transmitted to an Atomic Instrument Company 520, 20-channel differential pulse-height analyzer equipped with a Model 312, super stable high-voltage supply operated at 840 volts.

The gamma spectrum for each sample was corrected for crystal efficiency by taking the number of counts per second in each channel and dividing that number by the efficiency of the NaI(T1) crystal (Reference 17) for the gamma energy corresponding to that channel. This normalized the original spectrum to 100-percent crystal efficiency. All the normalized counts per second for each channel were then added giving the total number of events occurring in the crystal over all energies. The same procedure was applied to a standard Na^{24} spectrum, and this spectrum was superimposed on the spectrum of the sample. The sum of the events occurring in the crystal resulting from Na^{24} was then divided by the sum of the events resulting from the original sample. This gave the percent contribution of Na^{24} to the total gamma activity of the original sample. The method is estimated to be accurate within ±40 percent.

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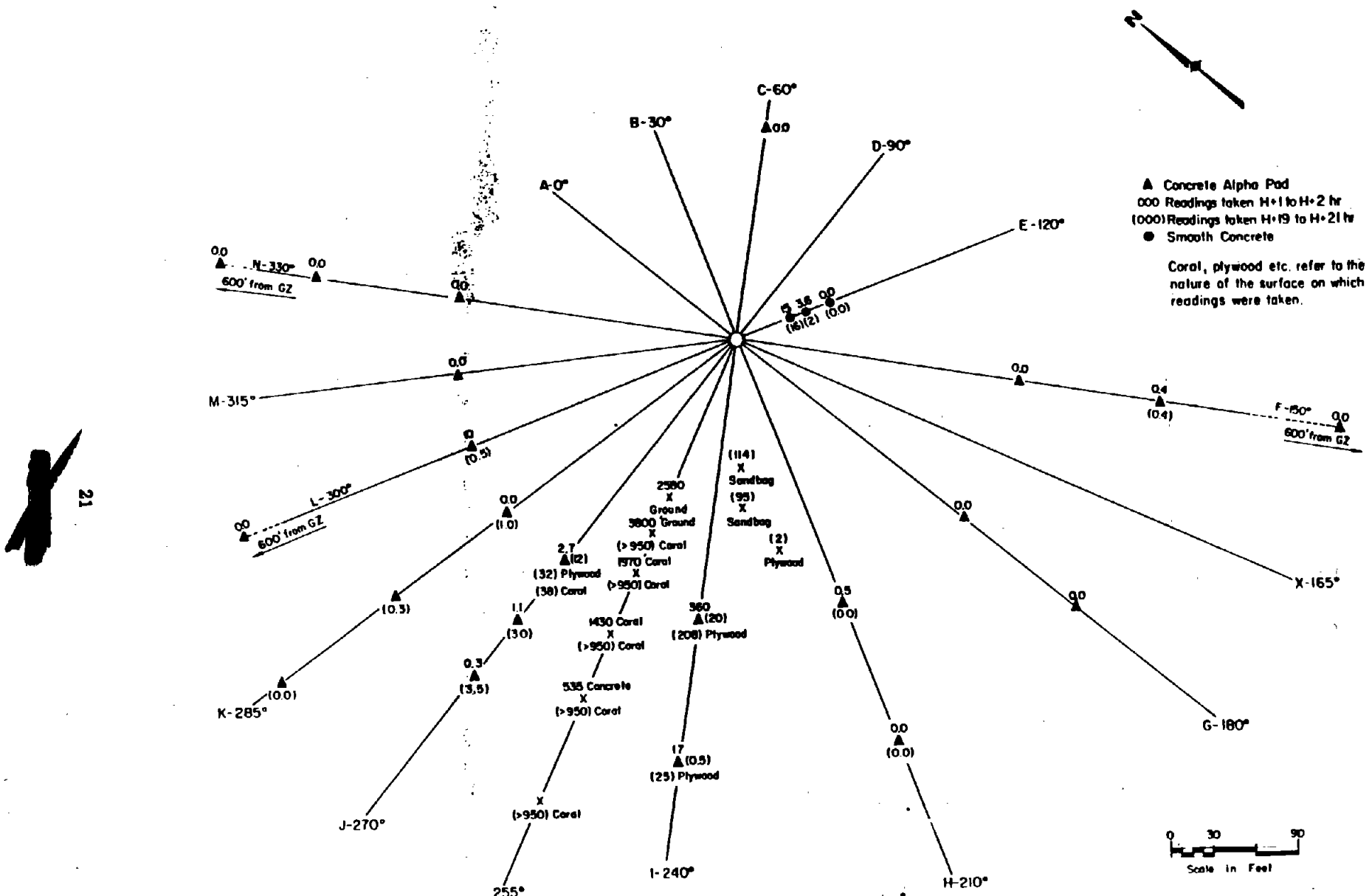

Figure 3.1 Alpha survey readings in $\mu g/m^2$, Shot Quince.

were apparently caused by the passage of the cloud. The probe during this time was located at its original position, 375 feet from ground zero on an azimuth of 317 degrees. The probe apparently moved no farther than 50 feet toward ground zero. When the instrument was recovered, the cable was found to have been tangled and broken by Sandia Corporation's sled cable. Also the glass front on the Brown recorder had been shattered, probably by the blast.

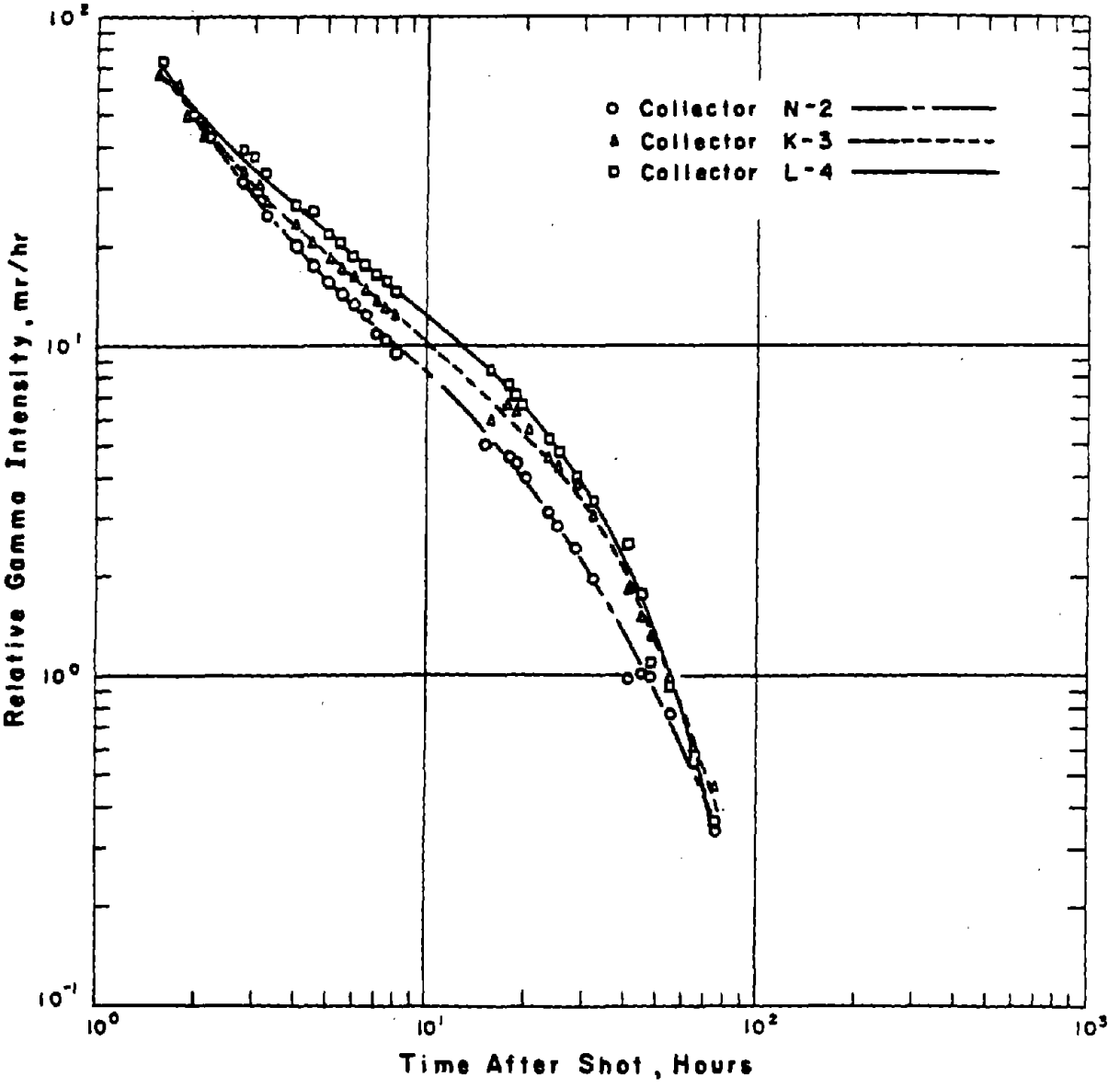

Figure 3.2 Decay curves for fallout samples, K-3, L-4, and N-2 normalized to H+1.98 hour, Shot Fig.

3.2.4 Alpha Survey. No detailed alpha survey was made. A rough survey indicated no increase of the alpha contamination due to Shot Fig, only redistribution. The results of the air samples are presented in Table 3.3. These readings do not represent the alpha concentration from the Fig device, because the area was already contaminated with alpha emitters from Shot Quince.

3.2.5 Weight and Activity of Fallout. The amount of fallout collected in grams per square centimeter and its relative radiation intensities are given in Figure 3.5. It can be seen that the weight collected decreased with distance. The greatest amount of fallout was collected on the

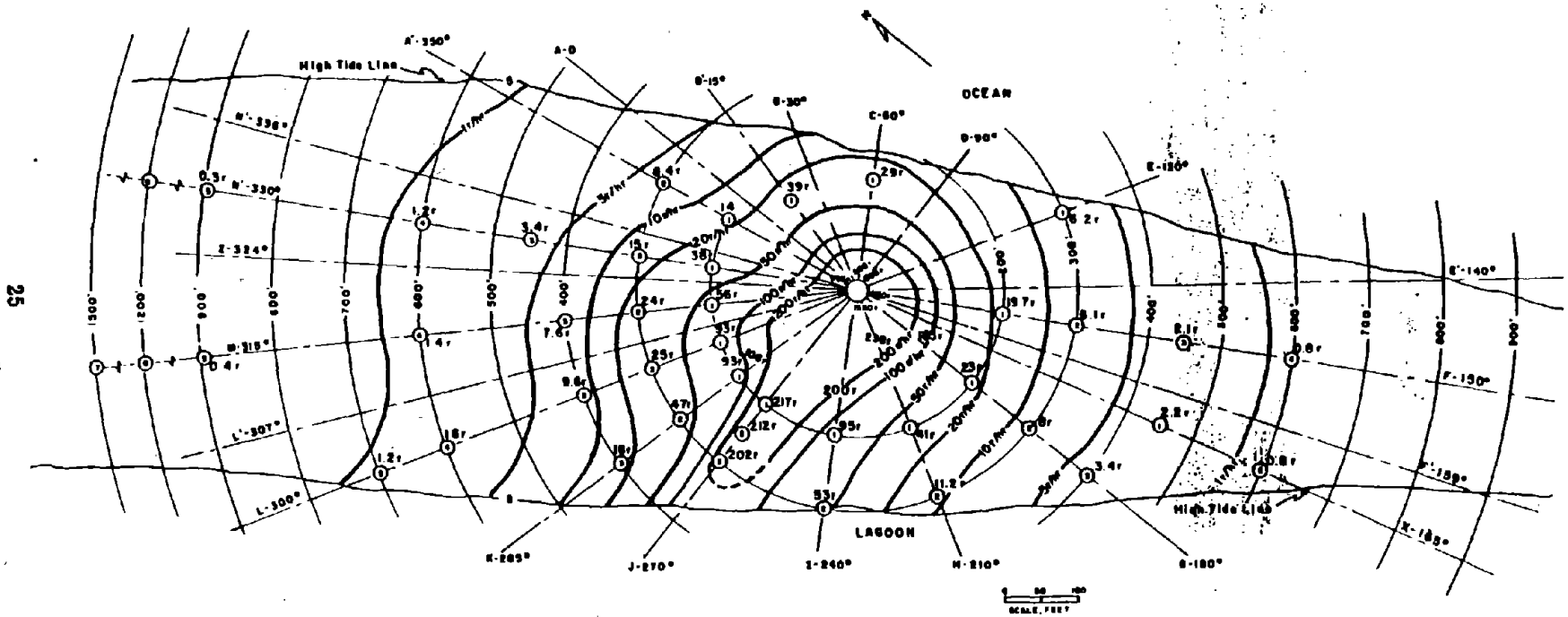

Figure 3.4 Dose rate in r/hr at H+1 hour, Shot Fig.

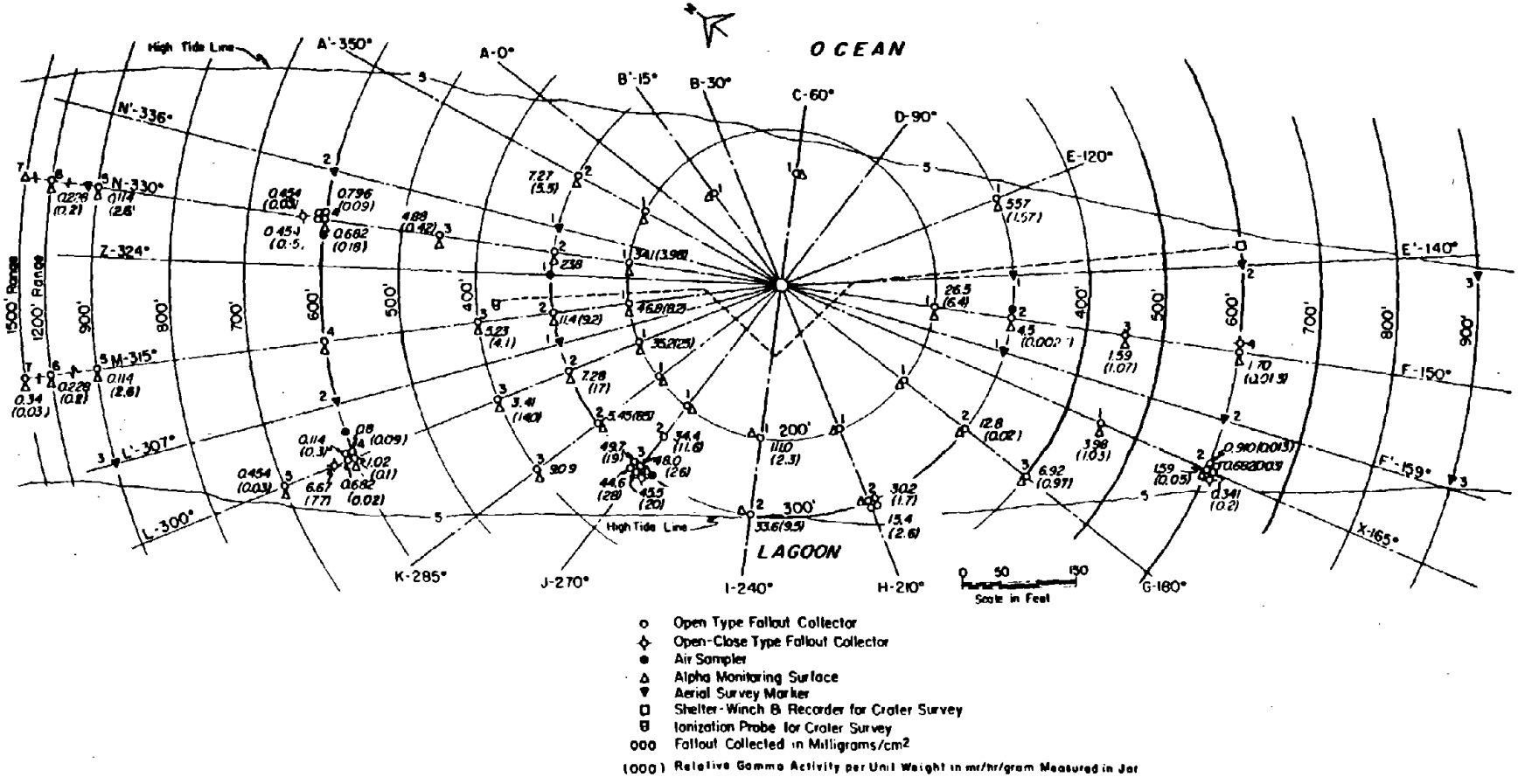

Figure 3.5 Weight of fallout and relative gamma activity, Shot Fig.

3.2.7 Beta-Activity Concentration. The beta-activity concentrations at the three stations are shown in Table 3.6. At K-3, the close downwind station, the Mo^{99}, Ba^{140}, Ce^{144} results decrease with increasing particle size up to 250 microns and then increase. For the larger-than-840-micron fraction, the values are higher by a factor of 50 than those for the other groups. At L-4, the more distant station, the Mo^{99}, Ba^{140}, Ce^{144} values were generally lower than at K-3. This tendency was especially pronounced in the larger-than-840-micron fraction. The values at N-2, the close crosswind station, are higher than the corresponding values for similar particle-size groups at K-3 except for the larger-than-840-micron group that showed values 7 to 10 times smaller than the results at K-3. The maximum activity concentrations at K-3 and N-2 are always in either the 420-to-840-micron group or the larger-than-840-micron group.

TABLE 3.6 BETA-ACTIVITY CONCENTRATIONS IN FALLOUT SAMPLES, SHOT FIG

Station	Size Fraction	Microcuries/Milligram At Zero Time								Total Beta Activity At H + 240 Hours
		Mo^{99}		Ba^{140}		Ce^{144}		Sr^{89}		
	microns	10^{-4} μc/mg	± pct σ	10^{-4} μc/mg	± pct σ	10^{-4} μc/mg	± pct σ	10^{-4} μc/mg	± pct σ	(counts/min)/mg
K-3	<149	61.2	± 2.9	42.3	± 2.2	22.5	± 29	10.7	± 2.9	728
	149 to 177	59.2	± 3.1	29.3	± 1.8	17.3	± 13	—	—	527
	177 to 210	40.1	± 3.5	20.8	± 3.7	11.8	± 3.1	—	—	396
	210 to 250	17.1	± 0.6	8.6	—	—	—	—	—	149
	250 to 297	49.1	± 4.0	25.1	± 7.2	17.0	± 15	6.53	± 4.7	446
	297 to 350	38.6	± 2.0	20.0	± 5.6	—	—	6.58	± 12	448
	350 to 420	46.1	± 1.2	23.2	± 0.1	—	—	6.95	± —	399
	420 to 840	225	± 3.1	82.2	± 0.1	47.3	± 8.7	19.2	± 4.1	1,469
	>840	996	± 9.6	482	± 3.8	279	± 5.1	82.9	± 3.6	1,209
Unsieved sample		25.7	± 3.1	12.7	± 1.8	11.8	± 41	2.48	± 6.4	250
L-4	<149	22.0	± 2.2	16.0	± 5.0	6.17	± 10	6.00	± 16	218
	149 to 177	13.2	± 0.1	9.10	± 5.0	4.86	± 9.2	—	—	177
	177 to 210	19.4	± 2.6	12.0	± 4.8	6.13	± 10	—	—	242
	210 to 250	14.7	± 5.7	11.7	± 4.9	3.82	± 19	4.50	± 0.3	265
	250 to 297	9.82	± 20	8.20	± 4.5	3.86	± 33	9.05	± 17	144
	297 to 350	14.1	± 8.7	10.2	± 9.7	4.14	± 6.0	4.55	± 18	166
	350 to 420	14.2	± 6.3	12.2	± 12	6.31	± 12	3.74	± 19	276
	420 to 840	14.5	± 2.3	8.47	± 0.2	4.16	± 5.5	3.78	± 39	155
	>840	8.23	± 5.2	7.30	± 25	2.80	± 24	5.81	± 23	103
Unsieved sample		25.3	± 3.1	11.4	± 2.6	6.22	± 25	3.78	± 2.0	206
N-2	<149	119	± 2.5	51.8	± 1.6	24.9	± 24	9.95	± 2.2	961
	149 to 177	113	± 1.1	51.4	± 5.8	26.2	± 6.6	12.9	± 35	915
	177 to 210	85.7	± 5.3	53.3	± 4.1	29.5	± 3.8	11.5	± 2.8	1,023
	210 to 250	125	± 1.0	60.6	± 0.2	33.4	± 7.5	19.5	± 2.6	793
	250 to 297	157	± 5.3	59.3	± 11	59.9	± 4.3	11.9	± 6.7	1,265
	297 to 350	186	± 2.5	86.7	± 2.9	—	—	6.08	± 1.0	1,858
	350 to 420	236	± 2.4	123	± 22	—	—	20.7	± 12	2,005
	420 to 840	439	± 5.8	147	± 8.3	105	± 5.9	29.8	± 5.0	2,350
	>840	130	± 3.3	70.2	± 4.8	26.7	± 4.7	13.7	± 1.5	961
Unsieved sample		273	± 0.6	144	± 8.2	104	± 4.1	4.50	± 6.4	3,182

3.2.8 Relative Contribution of Nuclides to Total Beta Activity. The relative contribution of nuclides to total beta activity at H+240 hours is shown in Table 3.7. At that time, the percentage of total activity contributed by the nuclides analyzed amounted to 28 to 69 percent of the beta activity present. It is possible that the iodine and ruthenium fission products were driven off by the procedure used to dissolve the sample; therefore, the percentages indicated may be high.

There appeared to be no well-defined trends of the percent contribution of individual nuclides to beta activity with particle size. However, it appears that the ratio of Mo^{99} to total beta activity is generally greater at the closer stations, K-3 and N-2, than at L-4.

3.2.9 R-Values. The R-values are shown in Table 3.8. The R-values, in general, showed no well-defined trend with particle size or location. The R-values for cerium/molybdenum were more constant at all stations than the R-values of other nuclides.

3.2.10 Gamma Spectrum. At H+51 hours, the gamma-ray spectrum of aliquots of fallout samples from Stations K-3, L-4, and N-2, showed a very prominent Na^{24} spectrum. These spectra were still identifiable at H+92 hours but not at D+6 days.

The analysis of the NTS soil is given in Table 3.9. The amount of sodium reported in the analysis may be low. The soil sample was taken when the soil was placed in the crater; however, this was several weeks before Shot Fig. During the interval, more NaCl could have been introduced into the soil from the environment.

TABLE 3.8 R-VALUES FROM FALLOUT, SHOT FIG

R-value is defined as $(A_a/B_a)/(A_{th}/B_{th})$ where the subscript a refers to any nuclear event and the subscript th refers to thermal neutron fission of uranium. B is usually Mo^{99} but can be any other nuclei.

Station	Size Fraction	$\frac{Sr^{89}/Mo^{99}}{Sr^{89}_{th}/Mo^{99}_{th}}$	± pct σ	$\frac{Ba^{140}/Mo^{99}}{Ba^{140}_{th}/Mo^{99}_{th}}$	± pct σ	$\frac{Ce^{144}/Mo^{99}}{Ce^{144}_{th}/Mo^{99}_{th}}$	± pct σ	$\frac{Sr^{89}/Ce^{144}}{Sr^{89}_{th}/Ce^{144}_{th}}$	± pct σ	$\frac{Ba^{140}/Ce^{144}}{Ba^{140}_{th}/Ce^{144}_{th}}$	± pct σ
	microns	pct		pct		pct		pct		pct	
K-3	<148	0.045	± 6.1	0.32	± 5.8	0.89	± 30	0.050	± 29	0.36	± 29
	148 to 177	—	—	0.23	± 5.7	0.70	± 14	—	—	0.32	± 13
	177 to 210	—	—	0.24	± 6.8	0.71	± 6.5	—	—	0.34	± 5.4
	210 to 250	—	—	0.23	—	—	—	—	—	—	—
	250 to 297	0.034	± 7.7	0.24	± 9.4	0.84	± 16	0.041	± 16	0.28	± 17
	297 to 350	0.044	± 12	0.24	± 7.4	—	—	—	—	—	—
	350 to 420	0.032	—	0.22	± 7.8	—	—	—	—	—	—
	420 to 840	0.22	± 6.8	0.19	± 5.4	0.50	± 10	0.043	± 10	0.37	± 9.2
	>840	0.021	± 11	0.23	± 11	0.69	± 12	0.031	± 6.7	0.34	± 6.8
Weighted average		—	—	0.24	—	—	—	—	—	—	—
Unsieved sample		0.025	± 4.9	0.23	± 5.7	1.1	± 25	0.022	± 41	0.20	± 41
L-4	<148	0.058	± 17	0.33	± 7.0	0.68	± 11	0.086	± 19	0.49	± 12
	148 to 177	—	—	0.32	± 6.7	0.89	± 10	—	—	0.36	± 11
	177 to 210	—	—	0.28	± 7.0	0.76	± 12	—	—	0.37	± 12
	210 to 250	0.078	± 7.2	0.36	± 8.7	0.82	± 20	0.12	± 19	0.58	± 20
	250 to 297	0.24	—	0.41	± 21	0.97	± 39	0.25	—	0.40	± 33
	297 to 350	0.082	± 21	0.33	± 14	0.71	± 12	0.12	± 20	0.47	± 12
	350 to 420	0.067	± 14	0.39	± 14	1.1	± 20	0.063	± 22	0.37	± 17
	420 to 840	0.067	± 40	0.27	± 4.9	0.69	± 7.5	0.096	± 40	0.39	± 6.0
	>840	0.18	± 24	0.41	± 26	0.82	± 25	0.22	± 33	0.50	± 34
Weighted Average		—	—	0.35	—	0.77	—	—	—	0.45	—
Unsieved sample		0.039	± 4.9	0.21	± 5.2	0.68	± 25	0.065	± 25	0.35	± 25
N-2	<148	0.021	± 5.6	0.20	± 5.4	0.51	± 24	0.042	± 38	0.40	± 24
	148 to 177	0.029	± 35	0.21	± 7.4	0.56	± 8.1	0.052	± 35	0.37	± 9.1
	177 to 210	0.034	± 7.5	0.29	± 8.0	0.83	± 8.0	0.042	± 27	0.34	± 6.0
	210 to 250	0.040	± 8.8	0.22	± 4.6	0.64	± 5.2	0.062	± 8.3	0.34	± 7.9
	250 to 297	0.020	± 9.6	0.17	± 13	0.92	± 8.2	0.021	± 8.3	0.19	± 12
	297 to 350	0.0085	—	0.21	± 5.9	—	—	—	—	—	—
	350 to 420	0.022	—	0.24	± 22	—	—	—	—	—	—
	420 to 840	0.018	± 8.9	0.15	± 11	0.58	± 9.5	0.030	± 8.1	0.27	± 10
	>840	0.027	± 5.7	0.25	± 7.4	0.50	± 7.3	0.054	± 5.4	0.50	± 7.1
Weighted average		0.024	—	0.22	—	—	—	—	—	—	—
Unsieved sample		0.0042	± 7.8	0.24	± 9.4	0.91	± 6.1	0.046	± 7.9	0.26	± 9.4

3.2.11 Examination of Particles. Detailed examination of the particles was limited to the 420-to-840-micron group from Station N-2. The samples were first washed with water to remove silt that obscured the individual particles. Some of the samples were subsequently washed with 6N nitric acid, along with samples of native NTS soil. The effects of these washings are shown in Table 3.10.

For the acid wash, the threefold-greater loss in weight of the fallout compared to that of the native NTS soil indicated that the detonation displaced coral as well as the implanted NTS soil. This inference is supported by the observation of fallout particles derived from coral and by calcium analysis which showed 7 percent in NTS soil and 21 percent in the fallout.

For the water wash, the 11-percent increase in measured activity suggests that the silt screened out low-energy beta particles.

On the basis of microscopic examination, the water-washed fallout particles were classified into four types: (1) fused, (2) white or yellow opaque, (3) tan opaque, and (4) miscellaneous. Types 3 and 4 were also observed in native NTS soil. The distribution of the particle types by weight and activity is shown in Table 3.11.

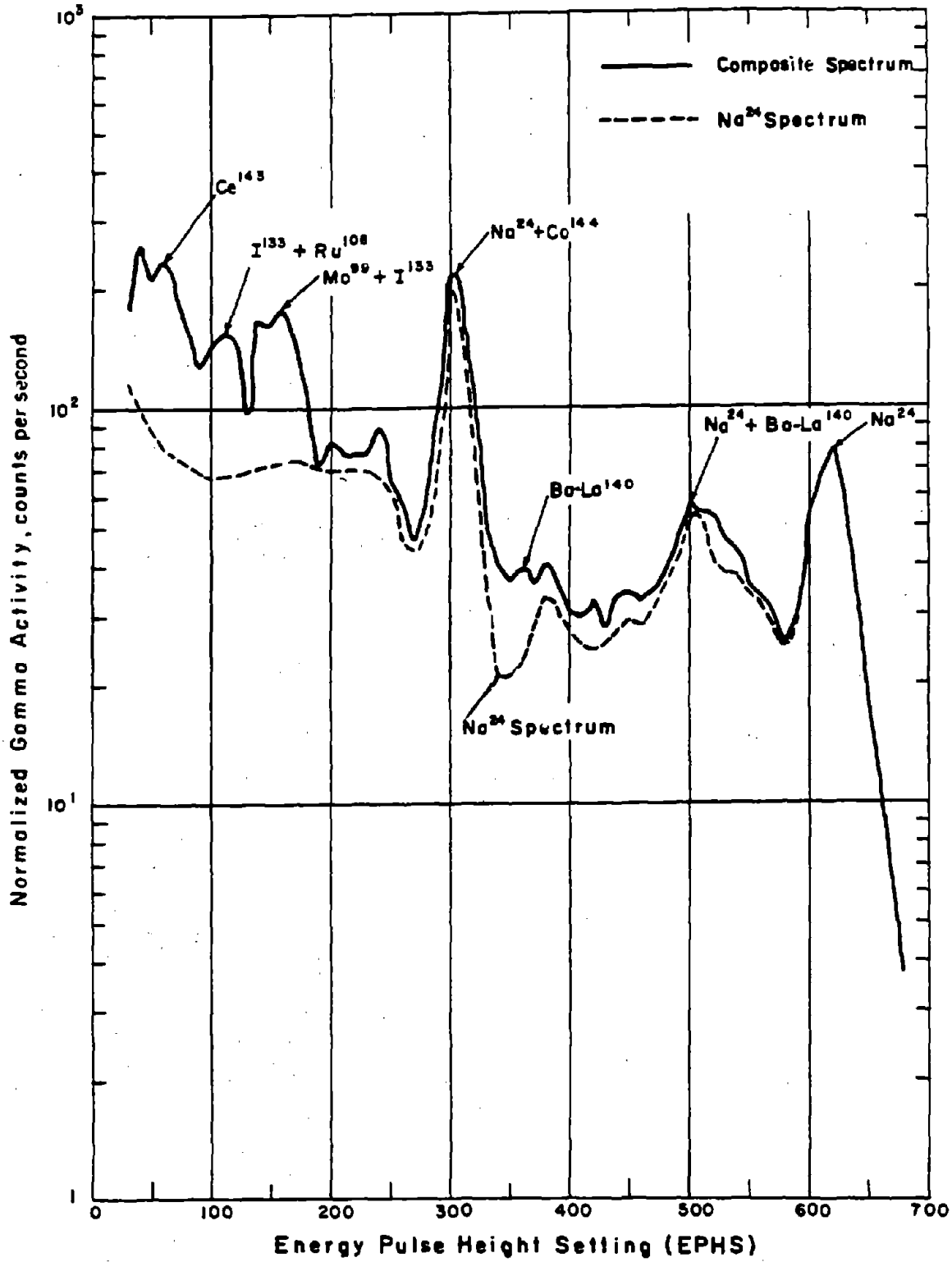

Figure 3.7 Normalized gamma spectrum at H+51 hours of fallout sample from Station L-4.

The fused particles (Type 1) are the most important from the standpoint of activity, as can be seen from Table 3.11. Although they occur in several forms, they have the common feature that at least one side of every particle is a clear, glassy material with green tints. Similar particles were observed during Operation Jangle (Reference 13). The various forms are: (1) particles of one material with only one side fused; (2) particles consisting of one material that

Figure 3.8 Fused fallout particle, 920 by 840 microns, magnified 62 times, photographed under transmitted light.

Figure 3.9 Fused fallout partucle, 880 by 1,080 microns, magnified 62 times, photographed with transmitted plus incident light.

is fused, with one or more particles of other materials impinged upon it; and (3) particles that are completely fused (all of these are very small). The fused material often contained small gas bubbles (Figures 3.8 and 3.9) and small grains of other material, usually black. Although the surfaces of the fused portions sometimes looked like bubbles or drops (Figures 3.9 and 3.10), they were more often of a flattened, convex form.

Figure 3.10 Fused fallout particle, 880 by 1,080 microns, magnified 62 times, photographed under transmitted light.

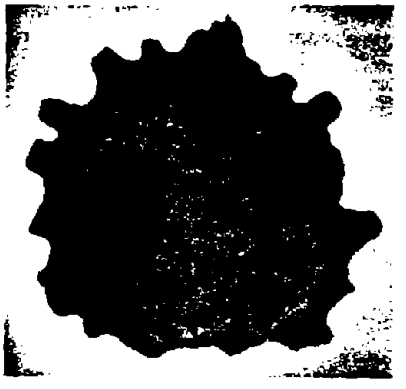

Figure 3.11 Oblate-spheroid fallout particle, 970 by 960 microns, magnified 62 times, photographed with transmitted light.

Two Type-1 particles were treated with seven successive small portions of 6N HNO_3. No change in their size or shape was observable under the microscope; however, the first washing leached off about 38 percent of the activity. Each of the remaining six washings removed only a little over 1 percent of the residual activity.

Upon treatment with concentrated HF at room temperature, the fused particles broke up into fragments. The dried fragments disintegrated into powder when they were pressed gently with a needle.

The insolubility of the fused particles in HNO_3 indicates that they were derived from the NTS soil (silicate). Their bubbly appearance suggests that they may have been heated above the boil-

Figure 3.15 Crystalline fallout particle, 1,050 by 1,100 microns, magnified 50 times, photographed with incident light.

Figure 3.16 Black preshot particle, 480 by 550 microns, magnified 55 times, photographed with incident light. (Note: Particle is nonmagnetic.)

Figure 3.17 Agglomerate preshot particle, 780 by 840 microns, magnified 62 times, photographed with incident light.

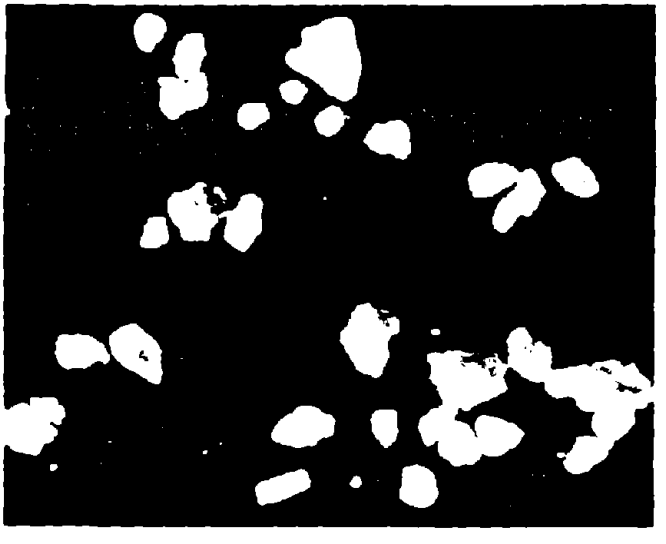

Figure 3.18 Fines from fallout fraction, less than 200 microns, magnified 62 times, photographed with incident light.

Chapter 4
CONCLUSIONS and RECOMMENDATIONS

4.1 CONCLUSIONS

DOE b(3)

4.1.1 Shot Quince. [redacted] Quince device under the same environmental conditions, it would be necessary to decontaminate a 30-degree sector out to a 300-foot radius in the downwind area.

4.1.2 Shot Fig. The lip and crater, resulting from the detonation of a weapon similar to the Fig device, would have a radiation intensity above 10,000 r/hr at H+26 minutes and would have to be avoided by troops advancing at an early time. If a weapon similar to the Fig device is fired under identical conditions, the present scaling laws can be used to determine the extent of the areas contaminated to 200 r/hr. The greatest amount of fallout was collected in the downwind area along a hot line, and the quantity decreased with distance.

The fallout consisted of NTS soil and coral particles, and fractions larger than 420 microns contained most of the activity. Although there is evidence that fractionation occurred with respect to particle size, distance, and azimuth, no definite trends were observed. Several types of particles were observed. However, fused silicate particles in the 420-to-840-micron fraction were only 9 percent of the total weight, but contributed 95 percent of the total activity.

4.2 RECOMMENDATIONS

Additional very-low-yield surface shots on a larger land mass are required to determine more accurately the level and extent of fallout and the contribution of the induced activity to the resulting dose rates.

[redacted]

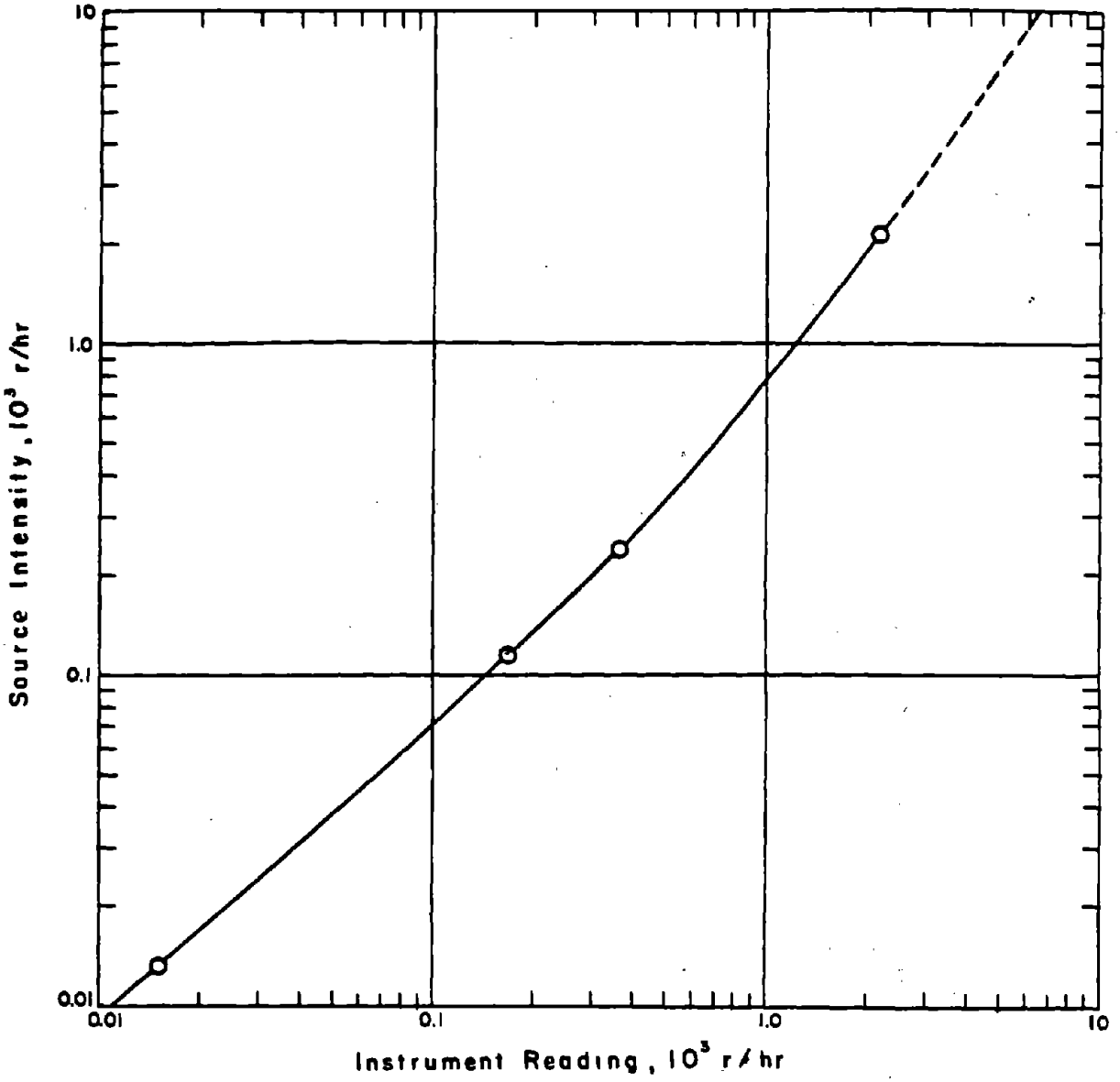

Figure A.1 Calibration curve for aerial-survey meter.

TABLE A.2 ALPHA SURVEY READINGS

Conversion factor: 420

Type of Surface Or Station	Location From Ground Zero		Time After Shot	Reading	Correction Factor	Corrected Reading	Alpha Concentration
	Azimuth	Distance					
	deg	ft	hr	counts/min		counts/min	$\mu g/m^3$
F-1, concrete pad	150	200	¾ to 2	0	2.1	0	0
F-2, concrete pad	150	300		70		147	0.4
F-4, concrete pad	150	600		0		0	0
G-1, concrete pad	180	200		0		0	0
G-2, concrete pad	180	300		0		0	0
H-1, concrete pad	210	200		100		210	0.5
H-2, concrete pad	210	300		0		0	0
I-1, concrete pad	240	200		72,500		152,000	360
I-2, concrete pad	240	300		3,350		7,000	17
J-1, concrete pad	270	200		550		1,155	2.7
J-2, concrete pad	270	250		225		470	1.1
J-3, concrete pad	270	300		50		105	0.3
K-1, concrete pad	285	200		0		0	0
L-1, concrete pad	300	200		2,000		4,200	10
L-4, concrete pad	300	600		0		0	0
M-1, concrete pad	315	200		0		0	0
N-1, concrete pad	330	200		0		0	0
N-2, concrete pad	330	300		0		0	0
N-4, concrete pad	330	600		0		0	0
C-1, concrete pad	60	150		0		0	0
Coral	255	225		150,000	4.0	600,000	1,430
Concrete, smooth	255	275		150,000	1.5	225,000	535
Coral	255	180		210,000	4.0	840,000	2,000
Ground	255	150		350,000	4.0	1,400,000	3,300
Ground	255	120		270,000	4.0	1,080,000	2,580
Concrete, smooth	120	40		4,250	1.5	6,375	15
Concrete, smooth	120	50		1,000	1.5	1,500	3.6
Concrete, smooth	120	70		0	1.5	0	0
F-2, concrete pad	150	300	19 to 21	75	2.1	160	0.4
H-1, concrete pad	210	200		0		0	0
H-2, concrete pad	210	300		0		0	0
I-1, concrete pad	240	200		4,000		8,400	20
I-2, concrete pad	240	300		100		210	0.5
J-1, concrete pad	270	200		2,400		5,040	12
J-2, concrete pad	270	250		650		1,360	3
J-3, concrete pad	270	300		700		1,470	3.5
K-1, concrete pad	285	200		200		420	1
K-2, concrete pad	285	300		50		105	0.3
K-3, concrete pad	285	400		0		0	0
L-1, concrete pad	300	200		100		210	0.5
Plywood	240	200		50,000	1.75	87,500	208
Plywood	240	300		6,000	1.75	10,500	25
Plywood	270	200		8,000	1.75	13,600	32
Coral	270	200		4,000	4	16,000	38
Coral	255	150		$>10^5$	4	$>4 \times 10^5$	>950
Coral	255	180		$>10^5$	4	$>4 \times 10^5$	>950
Coral	255	220		$>10^5$	4	$>4 \times 10^5$	>950
Coral	255	280		$>10^5$	4	$>4 \times 10^5$	>950
Coral	255	350		$>10^5$	4	$>4 \times 10^5$	>950
Sandbag	230	90		12,000	4	48,000	114
Sandbag	230	120		10,000	4	40,000	95
Plywood	220	150		500	1.57	875	2
Concrete, smooth	120	40		4,500	1.5	6,750	16
Concrete, smooth	120	50		500	1.5	750	2
Concrete, smooth	120	70		0	1.5	0	0
J-2, concrete pad	270	250	43	300	2.1	630	1.5

[redacted]

TABLE A.3 GAMMA DECAY READINGS OF FALLOUT SAMPLE FROM OPEN-CLOSE COLLECTOR, STATION L-4, SHOT FIG, AND COMPOSITE DECAY AFTER NORMALIZATION

Time After Shot	Gamma Readings	Gamma Values For Composite Decay Curve After Normalization Of Samples L-4, N-2, and K-3*
hr	mr/hr	mr/hr
1.55	73.5	70
1.75	61.5	61.6
1.97	50.7†	50.7
2.18	45.6	44.6
2.75	39.7	34.9
3.00	37.7	32.7
3.25	33.7	28.8
4.00	26.7	23.5
4.5	25.7	21.4
5.0	21.7	18.6
5.5	20.8	17.5
6.0	18.8	16.08
6.5	17.8	15.05
7.0	16.8	13.85
7.5	15.7	13.12
8.0	14.7	12.3
15.5	8.3	6.43
17.58	7.6	6.28
18.5	7.1	5.9
19.9	6.6	5.43
23.25	5.2	4.33
25.0	4.8	4.01
28.75	4.0	3.42
32	3.4	2.83
41	2.5	1.77
45	1.78	1.45
48	1.1	1.14
55	0.934	0.90
65	0.57	0.58
76	0.36	0.39

* Averages of all three samples using the normalized values.
† All three decay curves normalized to this time.

[redacted]

TABLE A.6 SUMMARY OF FALLOUT SAMPLES

Number	Sample In Bucket					Sample In Jars				
		Beta-Gamma Readings				Beta-Gamma Readings		Gamma Readings		
	Weight of Sample	Total Dose Rate	Time After H Hour	Weight Per Unit Area	Relative Activity Per Unit Weight	Total Dose Rate	Time After H Hour	Total Dose Rate	Time After H Hour	Gamma Relative Activity Per Unit Weight
	grams	mr/hr	hr	mg/cm²	(mr/hr)/gm	mr/hr	hr	mr/hr	hr	(mr/hr)/gm
A'-1	Not recovered									
B'-1	Not recovered - bucket blown away									
C-1	Not recovered - bucket crushed									
F-1	23.3	105	10.23	27	4.46	900	10.95	150	11.40	6.4
G-1	Not recovered - bucket overturned									
H-1	Not recovered - bucket blown away									
I-1	98.1	100	41.88	111	1.02	450	42.73	225	42.73	2.29
J-1	Not recovered									
K-1	Not recovered									
L-1	31.1	610	9.92	35	19.5	3,000	10.97	780	11.23	25
M-1	41.3	190	9.6	47	4.6	1,500	10.97	340	11.40	8.24
N-1	30.2	40	8.85	34	1.3	920	11.00	120	11.33	4
A'-2	6.4	11	10.13	7.3	1.7	130	10.88	36	11.37	5.6
E-1	4.9	25	10.33	5.6	5.05	190	11.47	70	11.47	15.7
F-2	4.0	0.5	10.62	4.5	0.125	0.07	10.83	0.01	11.42	0.0024
G-2	11.3	1.0	10.50	12.8	0.089	1.0	10.97	0.23	11.43	0.02
H-2-1	26.6	17	42.07	30	0.64	230	42.67	45	42.67	1.7
H-2-2	Not recovered - bucket crushed									
H-2-3	13.6	15	42.17	15	1.08	220	42.65	35	42.65	2.6
H-2-4	Not recovered - bucket crushed									
I-2	29.6	125	42.22	34	4.2	1,100	42.68	280	42.68	9.5
J-2	30.3	130	41.88	34	4.3	1,100	42.73	350	42.73	11.5
J-3-1	40.1	350	42.27	46	8.7	2,100	42.63	800	42.63	20
J-3-2	39.2	450	42.12	45	11.5	2,600	42.67	1,100	42.67	28
J-3-3	43.7	370	42.33	50	8.5	2,300	42.70	850	42.70	19.5
J-3-4	42.1	425	41.93	48	10	2,800	42.70	1,100	42.70	26
202.05	Collector did not open (open-close collector at Station J-3)									
K-2	4.6	260	10.43	5.5	54	2,300	10.97	410	11.38	85
L-2	6.4	0.35	9.45	7.3	0.055	700	11.03	110	11.42	17.2
M-2	10	47	10.30	11	4.7	500	10.98	92	11.38	9.2
N-2	20.9	—	—	24	—	5,000	1.47	1,100	1.47	530
G-3	6.1	2.3	10.10	6.9	0.378	20	10.92	5.9	11.35	0.965
K-3	8.0	—	—	9.09	—	5,000	1.47	1,100	1.47	140
L-3	3.0	7.3	9.08	3.4	2.43	290	10.98	42	11.22	14
M-3	4.6	6.5	9.50	5.2	1.4	70	10.98	19.9	11.37	4.1
N-3	4.3	1.8	9.30	4.9	0.42	15	11.05	1.7	11.25	0.4
F-3	1.4	0.3	10.22	1.6	0.214	1.28	11.02	0.15	11.22	1.07
X-1	3.5	0.55	9.13	4.0	0.167		10.93	3.6	11.43	1.03

TABLE A.7 GAMMA GROUND-SURVEY READINGS

Station	Time of Survey After H Hour	Survey Reading (AN/PDR-39)	Survey Reading Corrected to H + 1 Hour	Average Survey Reading Corrected to H + 1 Hour
	hr	mr/hr	mr/hr	mr/hr
A'-1	19.87	600	15,600	
	23.58	380	12,300	14,000
A'-2	2.82	1,200	5,100	
	23.58	230	7,470	
	24.0	200	6,600	6,390
B'-1	19.93	1,500	39,000	39,000
C-1	19.63	1,000	25,600	
	23.58	1,000	32,500	29,000
E-1	1.75	1,600	4,140	
	3.08	1,300	6,040	
	19.63	280	7,150	
	23.28	220	7,050	
	24.0	180	5,940	
	45.88	70	7,000	6,220
F-1	1.67	7,000	15,100	
	3.08	4,600	21,400	
	19.58	800	20,400	
	23.27	600	19,600	
	45.88	220	22,000	19,700
F-2	1.67	2,000	4,300	
	3.00	1,300	5,860	
	19.58	250	6,400	
	23.76	220	7,200	
	24.0	200	6,600	
	45.88	60	6,000	6,060
F-3	3.08	440	2,030	
	19.53	80	2,040	
	23.25	75	2,400	
	45.83	21	2,100	2,140
F-4	1.58	340	880	
	2.83	210	894	
	19.53	36	918	
	23.25	27	865	
	24.0	22	725	
	45.83	10	1,000	847
X-1	2.92	430	1,870	
	23.28	80	2,560	
	45.93	22	2,200	2,210
X-2	2.83	210	894	
	19.83	25	677	
	23.30	23	736	
	45.93	8	800	777
G-1	19.82	800	20,800	
	23.32	650	20,800	
	45.94	270	27,000	22,900
G-2	3.00	1,800	8,100	
	20.00	275	7,300	
	23.32	230	7,350	
	24.0	260	8,580	
	45.94	85	8,500	7,970
G-3	1.67	1,400	3,015	
	3.00	900	4,040	
	23.30	105	3,360	
	45.94	33	3,300	3,430
H-1	1.75	14,000	32,200	
	19.97	1,600	42,500	
	19.67	1,400	36,400	
	23.33	1,500	48,000	
	46.3	480	48,000	41,400
H-2	1.75	5,000	11,500	
	19.67	420	10,900	
	23.33	370	11,800	
	24.0	300	9,900	
	46.0	120	12,000	11,200
I-1	19.67	3,600	92,000	
	21.58	2,800	80,000	
	23.35	3,100	99,200	
	46.3	1,100	110,000	95,300

[redacted]

TABLE A.7 CONTINUED

Station	Time of Survey After H Hour	Survey Reading (AN/PDR-39)	Survey Reading Corrected to H + 1 Hour	Average Survey Reading Corrected to H + 1 Hour
	hr	mr/hr	mr/hr	mr/hr
N-2	0.58	36,000	14,400	
	19.83	800	20,800	
	23.5	480	15,350	
	24.0	340	11,200	
	46.5	130	13,000	14,950
N-3	19.97	140	3,710	
	23.5	95	3,040	
	46.5	33	3,300	3,350
N-4	0.5	3,400	1,020	
	2.92	300	1,320	
	23.52	41	1,310	
	24.0	35	1,150	
	46.5	14	1,400	1,240
N-5	2.95	50	220	
	23.52	8	288	254
N-6	2.97	24	107	
	20.05	9	238	173
A, on crater lip	46.5	8,000	832,000	832,000
A, crater lip interface	23.58	36,000	1,160,000	
	46.5	8,000	832,000	996,000
C, on crater lip	19.67	22,000	572,000	
	46.5	6,000	624,000	598,000
D, crater lip interface	23.58	25,000	805,000	805,000
E, on crater lip	46.5	6,000	624,000	624,000
E, crater lip interface	46.5	11,000	1,140,000	1,140,000
F, on crater lip	46.5	8,000	832,000	832,000
F, crater lip interface	46.5	11,000	1,140,000	1,140,000
G, on crater lip	19.67	40,000	1,040,000	
	46.5	11,000	1,140,000	1,090,000
G, crater lip interface	46.5	15,000	1,560,000	1,560,000
I, on crater lip	46.5	11,000	1,140,000	1,140,000
I, crater lip interface	46.5	15,000	1,560,000	1,560,000
G-0	23.67	2,800	90,200	
	46.5	2,700	280,000	185,100
H-0	23.67	8,000	258,000	
	46.5	2,100	218,000	238,000
I-0	23.67	6,000	193,000	
	46.5	2,000	208,000	200,000
J-0	23.67	4,500	145,000	
	46.5	2,000	208,000	166,000
K-0	23.67	2,700	86,800	
	46.5	1,200	125,000	105,900

Appendix B
RADIOCHEMISTRY

B.1 SAMPLE PREPARATION

The portions of fallout samples designated for radiochemical analysis were dried at 110 C for 1 hour and accurately weighed to ± 0.1 mg. The samples were pulverized in a mortar, then treated with concentrated HF, evaporated to dryness, treated with 70-percent perchloric acid, carefully fumed almost to dryness, and treated with 6N HCl. The liquid was separated from the solid material, and the above process was repeated on the solid material. Any solid material remaining after the second treatment was discarded. The liquid solutions were combined and diluted to an appropriate volume with distilled water.

B.2 RADIOCHEMICAL SEPARATION AND COUNTING

The details of the separation procedures are essentially the same as used during Operation Redwing (Reference 15). Generally, four aliquots were taken for each analysis, and the average of the four was reported. In the analyses for Sr^{89}, Mo^{99}, Ba^{140}, and Ce^{144}, the final precipitates were mounted in the centers of $3\frac{1}{4}$-by-$2\frac{1}{2}$-by-$\frac{1}{16}$- inch aluminum plates. The Ce^{144} precipitate was evenly spread in a $\frac{1}{32}$-inch depression, $\frac{5}{16}$-inch in diameter, in the center of the aluminum plate. In the other analyses, the final precipitates were filtered through $\frac{7}{8}$-inch-diameter filter papers, which were weighed to determine chemical yield and mounted in the center of the plates. A film of rubber hydrochloride (0.45 mg/cm^2) was placed over the samples to eliminate any rearrangement of the precipitate.

All beta counting was done with thin end-window GM tubes mounted in lead pigs, Technical Associates Model AL 14A. Scalers, Atomic Instrument Company Model 1060, were used to record counts. The GM tubes were supported by the usual lucite stages, in which the distances between the tube window and the absorber shelf, Shelf 1, Shelf 2, and Shelf 3, are 0.8, 1.5, 3.1, and 4.7 cm, respectively.

Each sample (except for Sr^{89}) was counted for a total of 10,000 counts or for a total counting time of 10 minutes. Ten thousand counts provide a 95-percent probability of being within 2 percent of the actual counting rate. The 10-minute time limit was expedient because of the large volume of counting that had to be done. The Sr^{89} samples were counted for 60 minutes because of low counting rates. All samples were counted through at least one half-life, except for Ce^{144}. The samples on the aluminum cards were counted with the same orientation at all times.

The individual nuclide activities were corrected for radioactive decay (to zero time), chemical yield, self-absorption, and self-scattering. Each tube was calibrated for correction of counting rates to disintegration rates by actual measurement of a standard source for each nuclide analyzed.

The gross beta activities of the dissolved samples were measured on small aliquots of dissolved samples evaporated to dryness in glass planchets or cups. A film of rubber hydrochloride was glued over the tops of the planchets to prevent the absorption of moisture. In most cases the amount of material was small enough to eliminate significant self-absorption and self-scattering corrections.

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